18th CRC ON-ROAD VEHICLE EMISSIONS WORKSHOP
March 31 – April 2, 2008, San Diego

CARB's Phase II Study: *Project Overview and NO_X, PM, and Nanoparticle Emissions*

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Acknowledgements:

CARB Lead Investigator: Research Division

CO-Investigators: CARB's Monitoring and Laboratory Division, CARB's Mobile Source Control Division, University of Southern California, UC Davis

Co-Sponsors:

In Kind Contributors:

Background and Motivation

- **CARB's longstanding scientific need/interest in policy-relevant assessment of HDV emissions**

- **In 2000, Dr. Alan Lloyd asked staff the question: *is diesel with a filter as "clean" as CNG?***
  - **Phase I: Study of emissions from CNG and clean diesel transit buses**
  - Successful 2001-2003 multi-division, multi-agency investigation
  - Half a dozen publications and a dozen invited presentations (many at CRC meetings)
  - Answer = YES, both were pretty clean, but can/have been made cleaner

- **Phase II builds on the *triumphs* and *defeats* of Phase I:**
  - Position CARB to advance *proactively* on emerging motor vehicle emissions issues:
    - Ultralow emissions from emerging technology and advanced aftertreatment
    - Measurement instrumentation and protocols
    - Relative toxicity of PM components (volatile vs. non-volatile fraction)
    - ACES
  - CARB needs data for 2010-like vehicles
  - The retrofit systems of today are a glimpse into the production-ready OEM systems of the future
  - Assessing emission reduction and toxicity relevant to the older system

Retrofit Device Test Matrix

4 vehicles, 8 configurations, 3 driving cycles

Vehicle	Aftertreatment	Abbreviation
Veh#1  1998 Cummins Diesel 11L, 360,000 miles	none	Baseline
	DOC → Uncatalyzed Filter — 50,000 mi	Veh #1 CRT®
	DOC → Uncatalyzed Filter — 50,000 mi; Urea → Vanadium SCR → Oxid Cat — 50,000 mi	Veh #1 V-SCRT®*
	DOC → Uncatalyzed Filter — 50,000 mi; Urea → Zeolite SCR → Oxid Cat — 0 mi	Veh #1 Z-SCRT®*

•**SCRT® systems used in this project are development prototypes not commercial units**.

Test Matrix (cont'd)

4 vehicles, 8 configurations, 3 driving cycles

Vehicle	Aftertreatment	Abbreviation
Veh#2, 1999 International Diesel		
 7.6L, 40,000 miles	Catalyzed Filter **30,000 mi**	**Veh#2 DPX**
	DOC + Uncatalyzed Filter **5,000 mi** (Only tested for nucleation)	**Veh#2 CRT2®**
Veh#3 2003 Cummins Diesel,		
 5.9L, 50,000 miles	Uncatalyzed Filter **31,000 mi**	**Veh#3 Horizon**
Veh#4 2006 Cummins Diesel w/ Allison Hybrid drive		
 5.9L, 1,000 miles	DOC + Catalyzed Filter **1,000 mi**	**Veh#4 CCRT®**

Experimental Setup @ CARB's HDV Emissions Laboratory

Dilution Air

CVS Tunnel
Q=2600 or 1600 cfm

Exhaust from Testing Vehicles

FTIR
N_2O, NH_3

Bags
Gases, VOCs

Sioutas Impactor@
V_2O_5

Filters
(+ vapor traps)
PM, PAHS, Nitro-PAHs, Ions, Trace elements, EC/OC, Mutagenicity

NanoMOUDI
PM, organics and Ions

HiVol Sampler
Organics, Ions, Redox activity

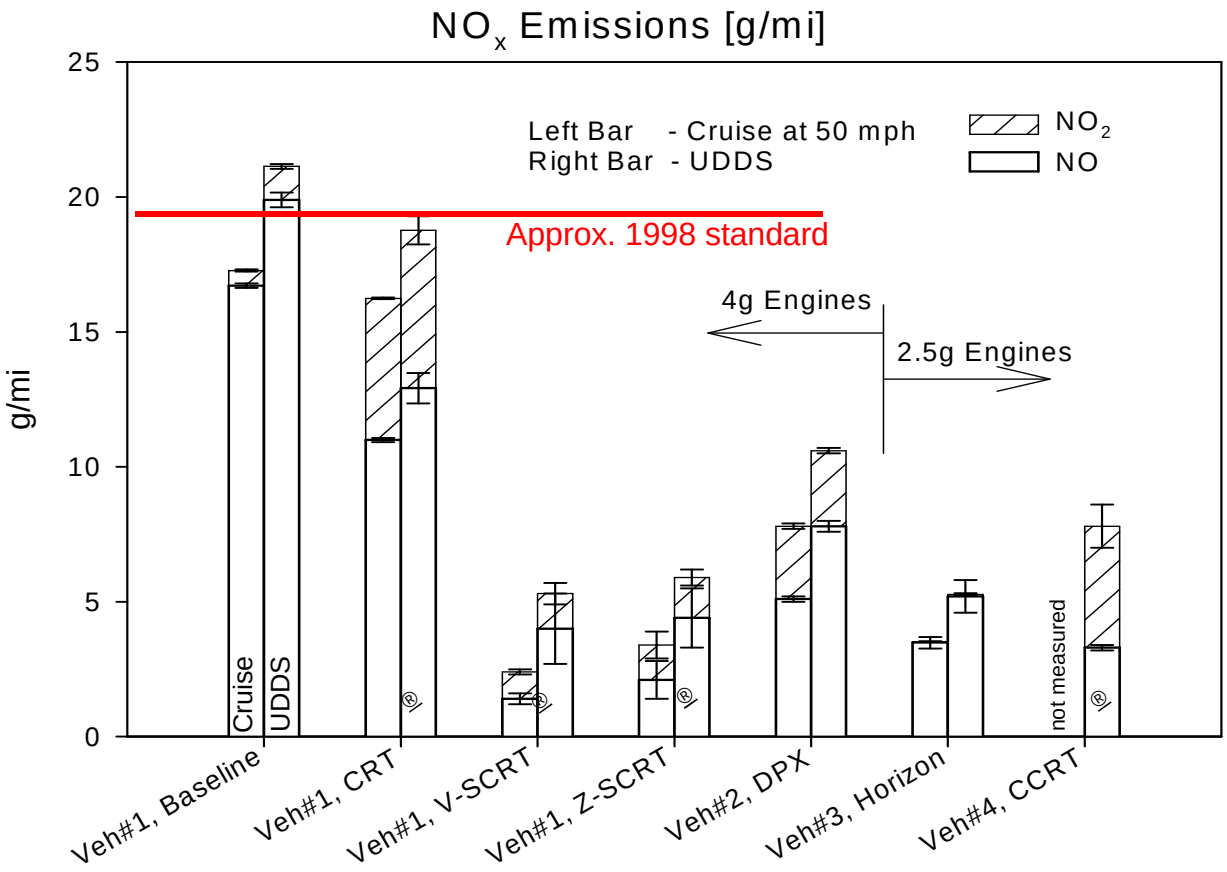
Cartridges
Carbonyls

Particle Characterization
EEPS, DMS, multiple CPCs, PAS, EAD

VACES
Biosampler (Suspension) and Chemical assay for redox activity and electrophilicity

Thermaldenuded Sample
Metals, Ions, Redox activity, **CPC**

NO_x Emissions



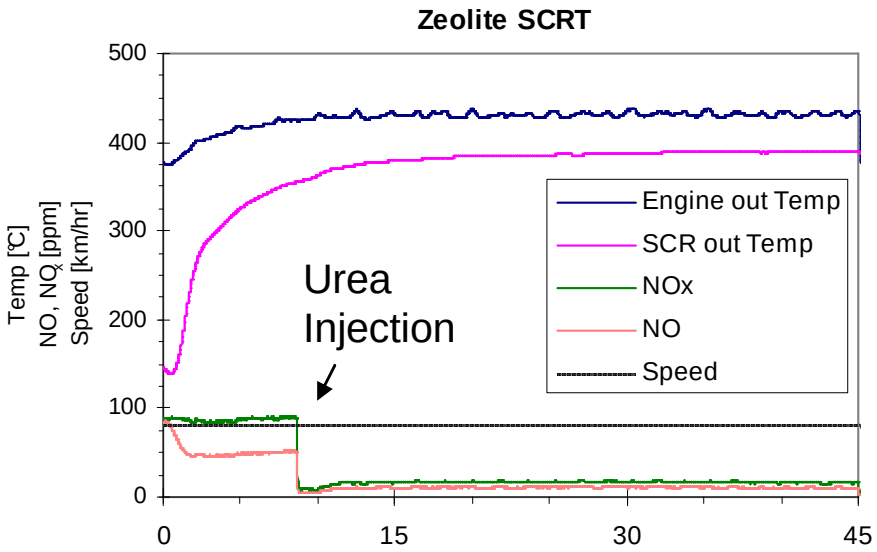
- SCR reduced NO_x by approximately 80% and 90% for UDDS and cruise cycles respectively
- Catalytic surfaces increase fraction of NO_2, to as much as 50% of NO_x for the CCRT®

Note: although not shown, during idle, no SCR NO_x reduction and NO_2:NO_X ratio is low in all configurations.

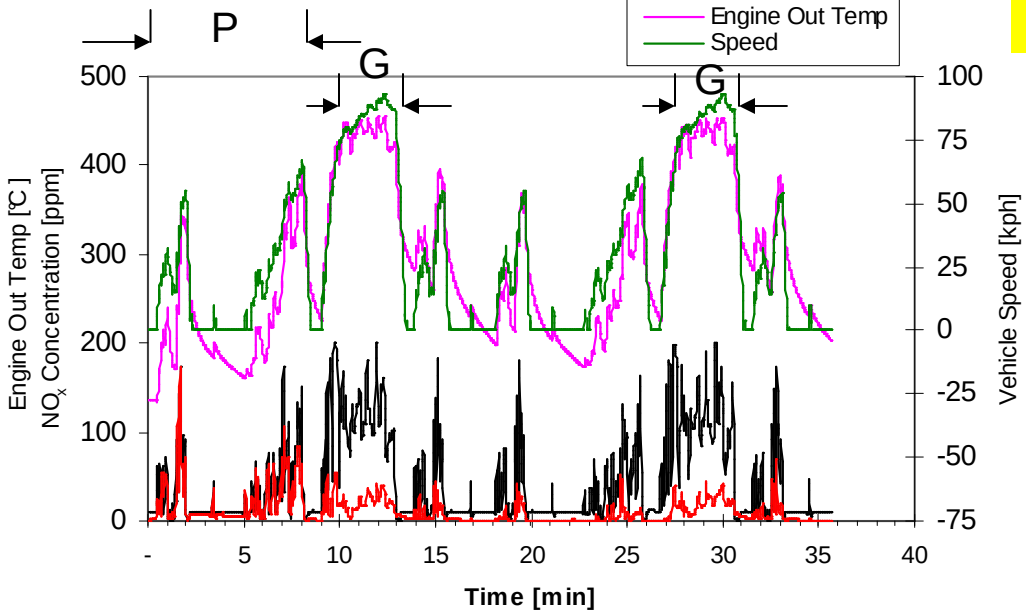
NOTE: Preliminary results

Realtime NOx Concentrations

a) Cruise 50mph



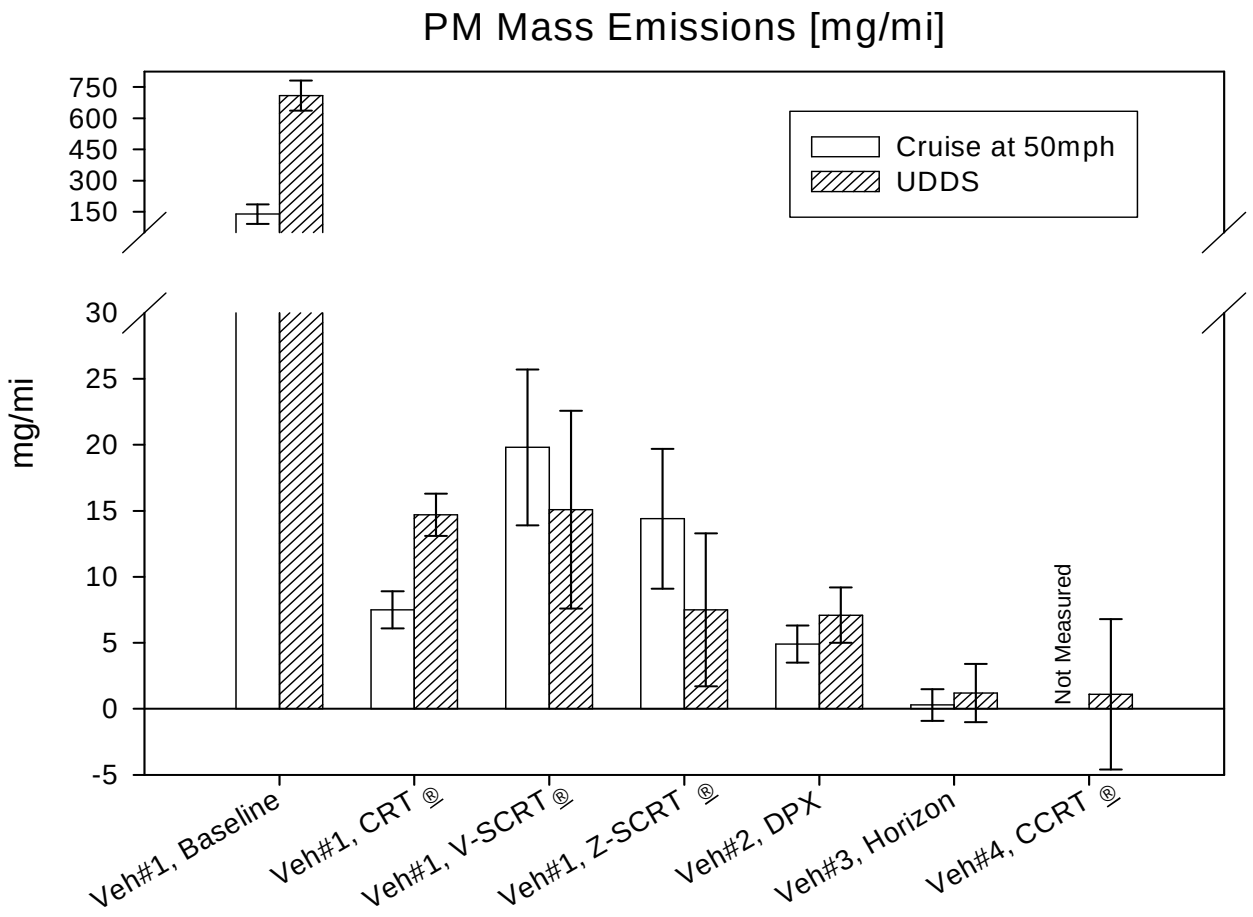
b) UDDS



- SCR reduction of NO_x is temperature dependent
- Good reduction during highway operation
- Poor reduction in stop-and-go activity

G: good NOx reduction
P: poor NOx reduction

PM Mass Emissions



- Aftertreatment in Veh#1 reduced PM emissions by 90+%
- Reductions were greatest for UDDS cycle
- In newer engines (Veh#3 and Veh#4) retrofits reduced PM to near LOD of gravimetric ref. method

Note: although not shown, DPFs reduced PM during idle >98%.

NOTE: Preliminary results

Much continued interest in ultrafine particle emissions

Environ. Sci. Technol. XXXX, xx

Cytotoxicity and Inflammatory Potential of Soot Particles of Low-Emission Diesel Engines

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Received July 5, 2007. Revised manuscript received November 27, 2007. Accepted December 3, 2007.

We evaluated, in vitro, the inflammatory and cytotoxic potential of soot particles from current low-emission (Euro IV) diesel engines toward human peripheral blood monocyte-

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Swiss Federal Institute of Technology Zurich

ETH Zürich - DMAVT - IET - LAV - 12th Conference

12th ETH-Conference on Combustion Generated Nanoparticles

The

12th ETH-Conference on Combustion Generated Nanoparticles

takes place

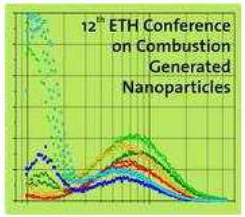
23. - 25. June, 2008

at ETH Zentrum, Zurich, Switzerland

Dear Colleagues,

Thank you all for your contribution to the 11th Conference on Combustion Generated Nanoparticles!

We invite you to the 12th Conference on Combustion Generated Nanoparticles scheduled at the ETH Zurich 23. - 25. June 2008.



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Evaluating the Toxicity of Airborne Particulate Matter and Nanoparticles by Measuring Oxidative Stress Potential—A Workshop Report and Consensus Statement

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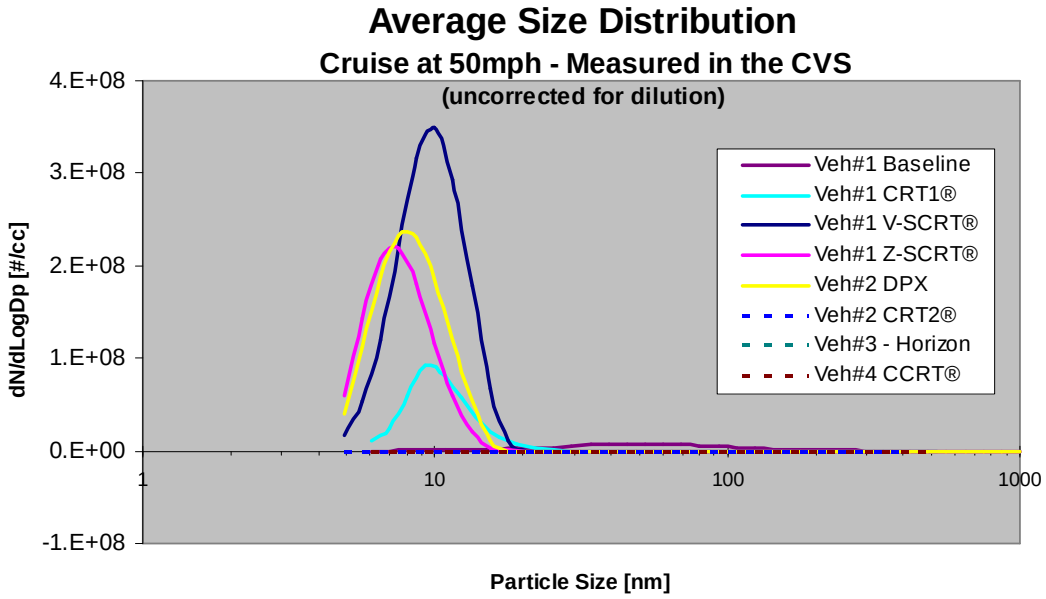
Average Size Distribution

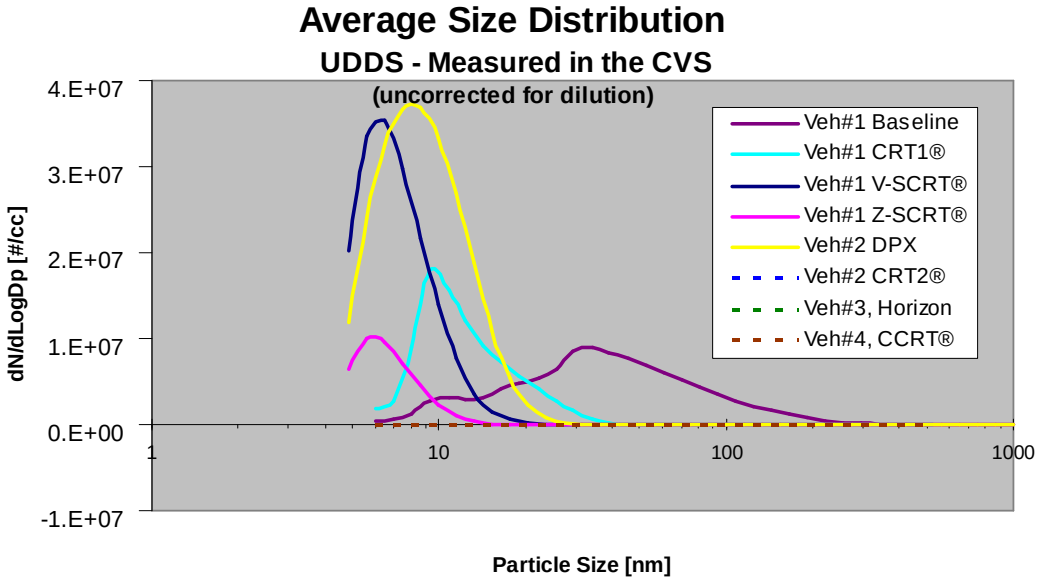


Accumulation mode seen in: Veh#1 Baseline

Nucleation mode seen in:
Veh#1 CRT1®
Veh#1 V-SCRT®
Veh#1 Z-SCRT®
Veh#2 DPX

NO nucleation mode in
Veh#1 Baseline
Veh#2 CRT2®
Veh#3 Horizon
Veh#4 CCRT®

Low mileage device



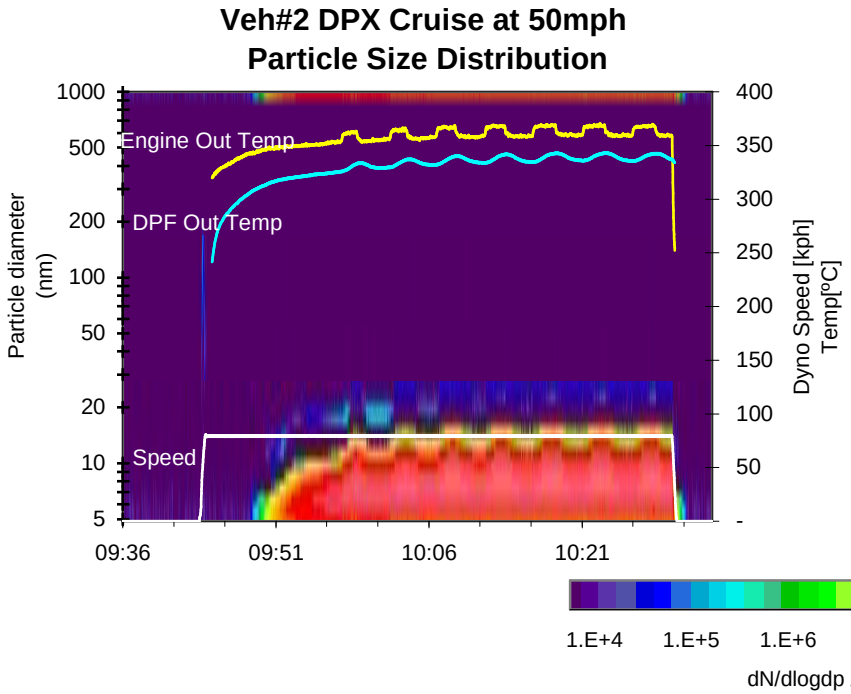
Nucleation appears to be neither vehicle nor device specific

NOTE: Preliminary results

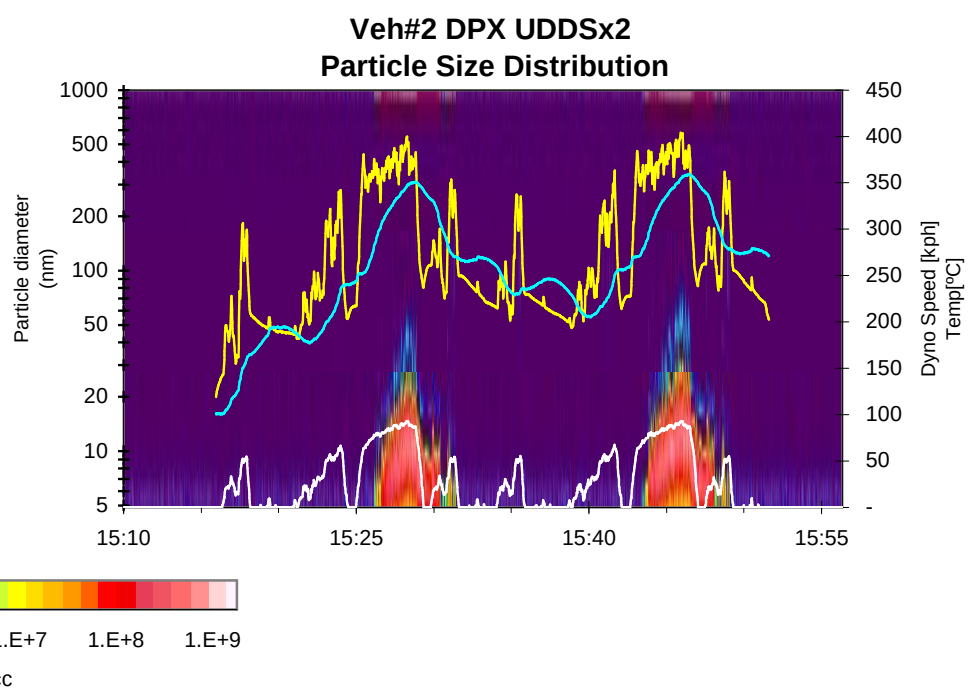
Ref: Herner et al., AAAR, Reno, **2007**

When Does Nucleation Occur?

Cruise @ 50 mph



UDDS



- Catalytic surfaces can store sulfate
- Conversion of SO_2 to SO_3 is temperature dependent

Each configuration emits nucleation mode particles once the post-aftertreatment exhaust reaches a ***critical temperature***:

T_{crit} Veh#1, V-SCRT® = 330ºC	T_{crit} Veh#1, Z-SCRT® = 373ºC
T_{crit} Veh#1, CRT1® = 373ºC	T_{crit} Veh#2, DPX = 315ºC

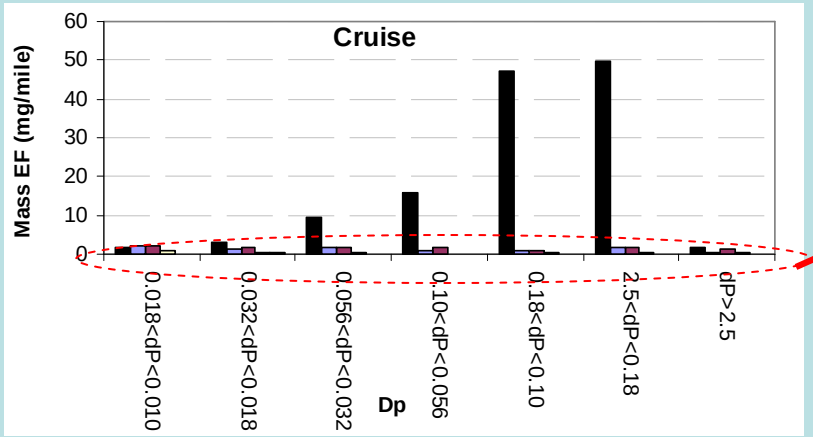
Ref: Herner et al., AAAR, Reno, **2007**

NOTE: Preliminary results

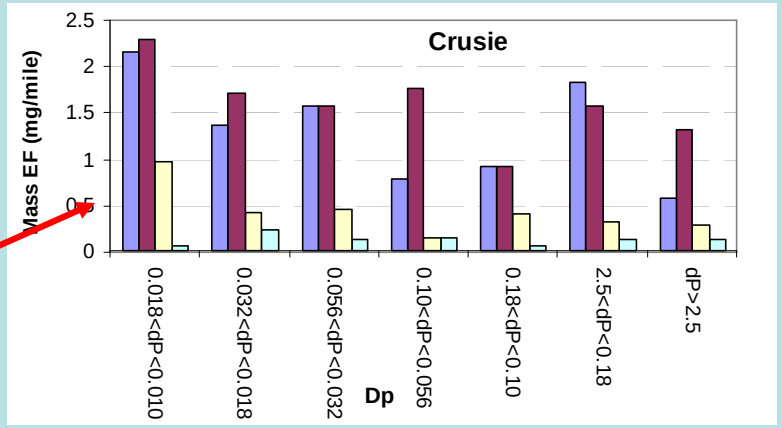
Particle Mass Size Distribution

Baseline | CRT® | V_SCRT® | Z-SCRT® | DPX | Horizon | CCRT®

CRUISE



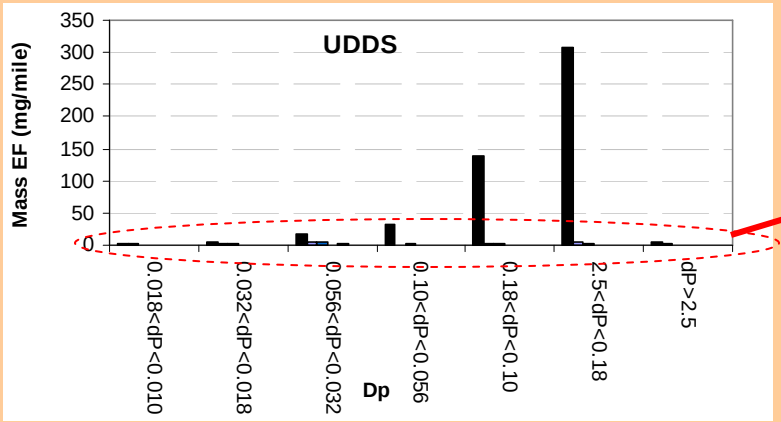
Nucleation → Coarse



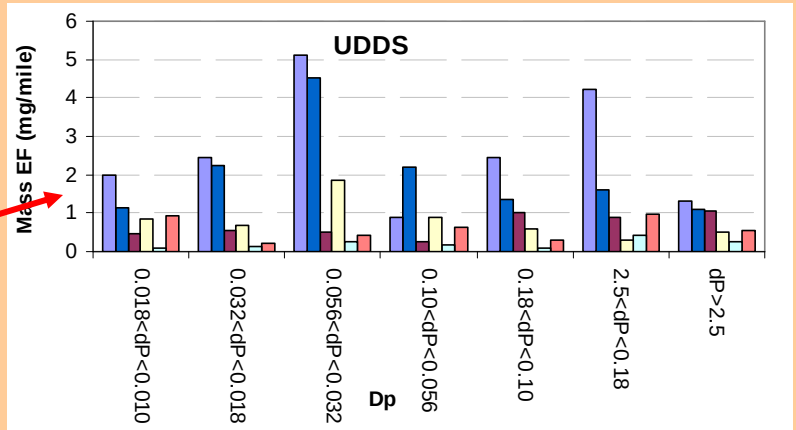
Nucleation → Coarse

- For vehicles with significant particle numbers in ultrafine range, mass is also emitted in the same range
- Baseline emissions mostly in coarse mode(> 100 nm range)

UDDS

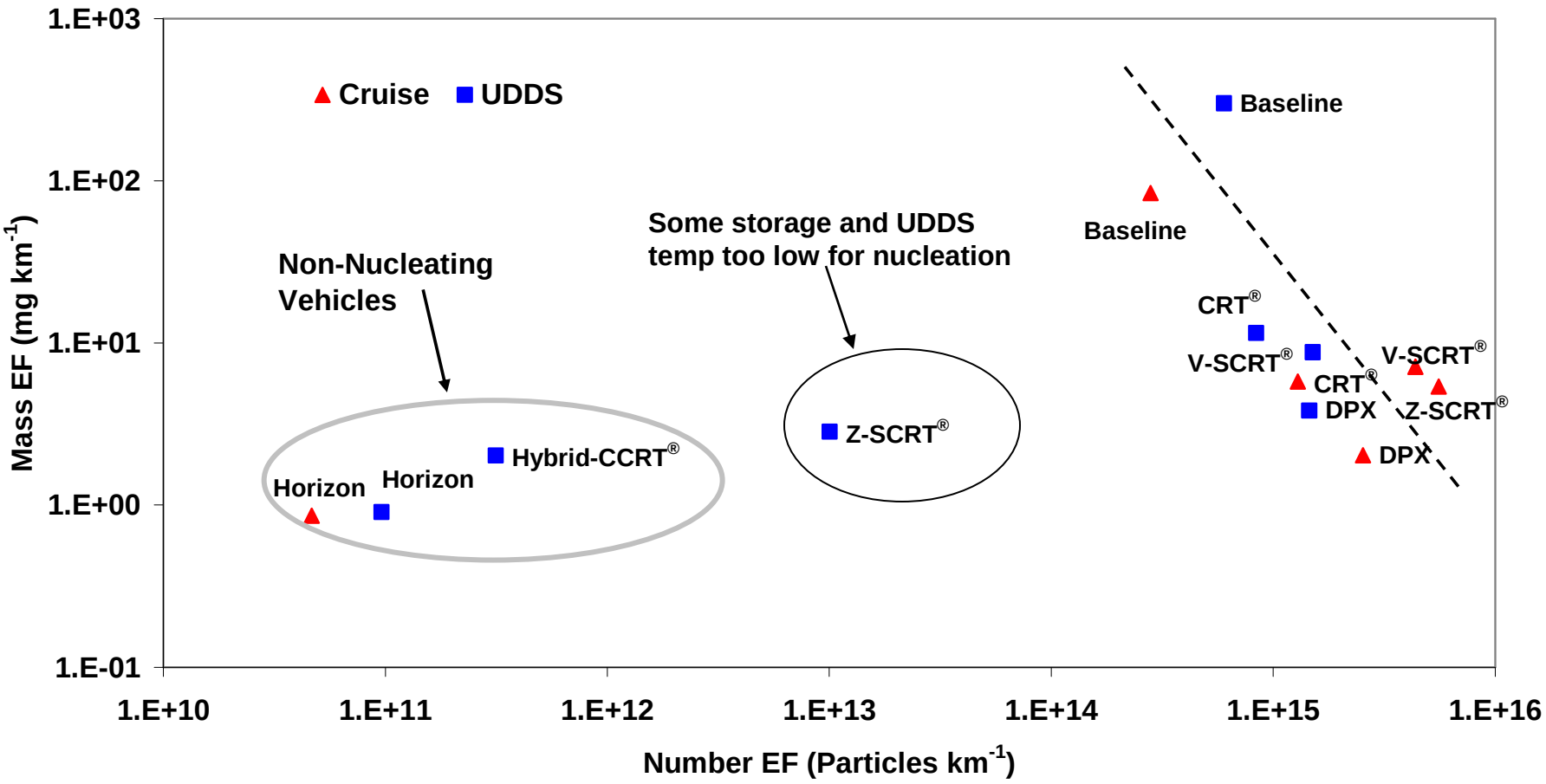


Nucleation → Coarse



Nucleation → Coarse

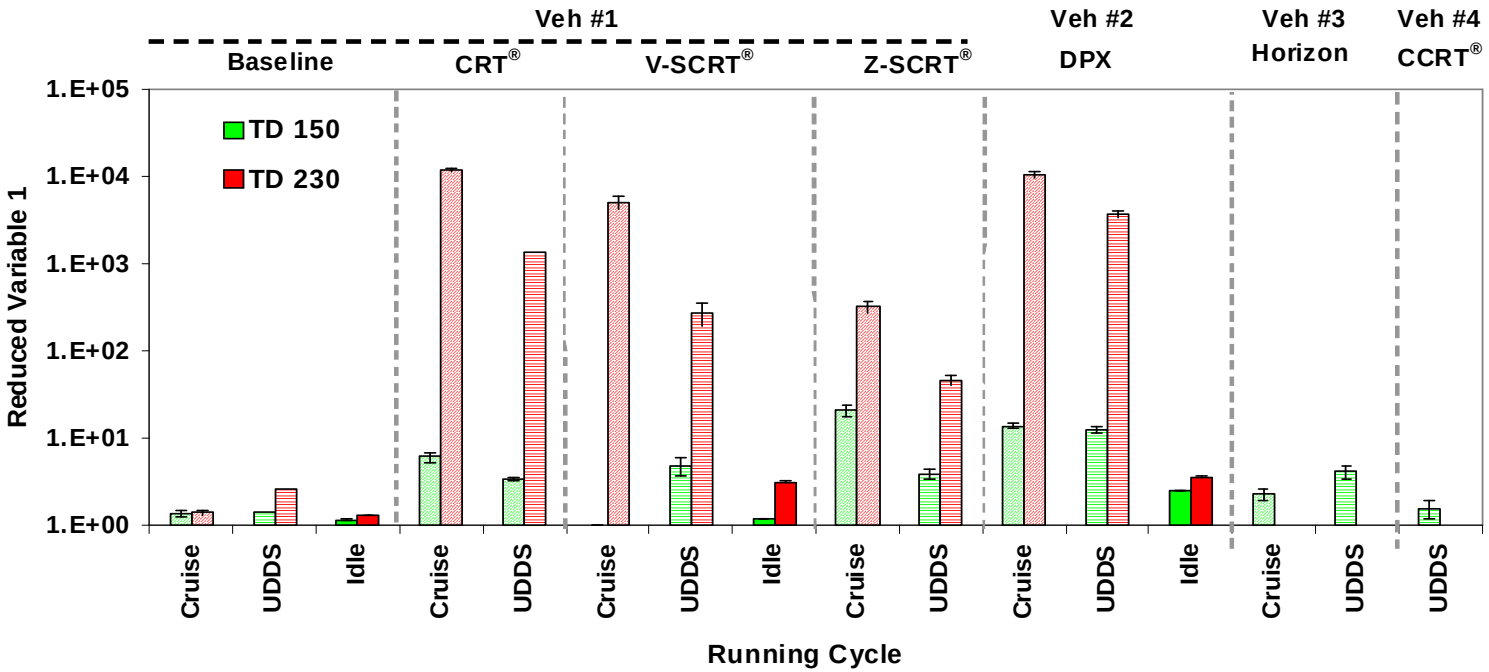
Number vs Mass Emission Factors

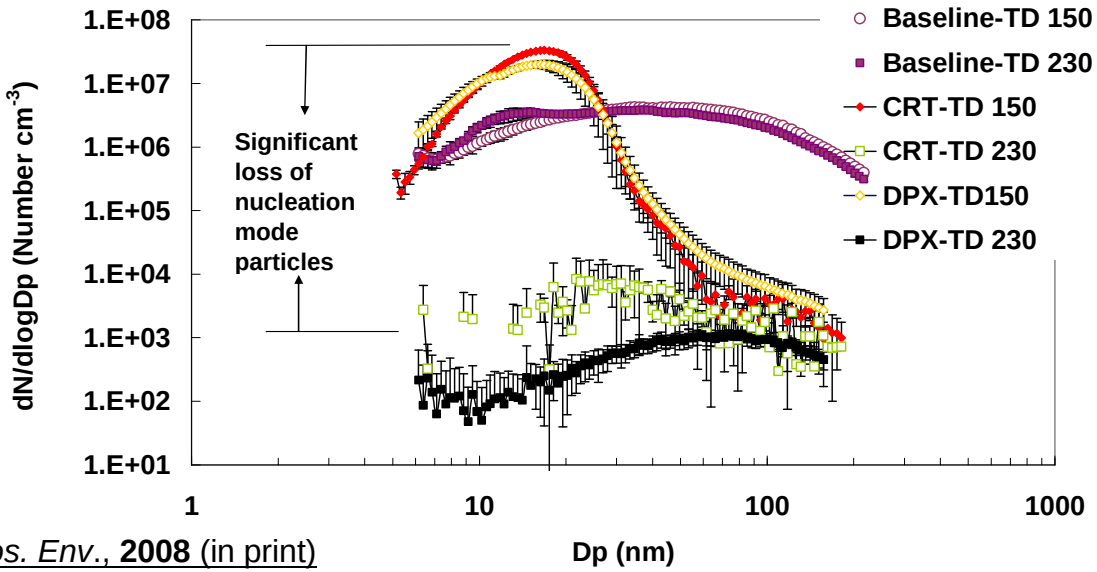


- Under certain conditions we saw reduced mass but enhanced number emissions
- Horizon and Hybrid (CCRT) (**without** nucleation mode particle formation) lie in the left corner in the figure suggesting reduction of both number and mass EF.

Ref: Biswas et al., *Atmos. Env.*, **2008** (in print)

Particle Volatility – Number Based $R = N_{Exhaust} / N_{TD}$





Ref: Biswas et al., *Atmos. Env.*, **2008** (in print)

Summary

- In general, retrofits are accomplishing their design intent
- SCR retrofits can reduce NO_X emissions better than 80%, except during cold cycles
- Remarkable reduction of PM mass emissions (>90%) by the retrofit devices tested
- Occasional formation of large number of nucleation mode particles by retrofits that contain catalytic surfaces
- Catalytic surfaces store sulfate for thousands of miles, suppressing nucleation
- Upon aging, retrofits promote nanoparticle formation when exhaust reaches a *critical temperature*
- For some retrofits, nucleation mode particle account for a significant fraction of mass emission in the same particle size range
- For some retrofits, total particle number emissions increased as mass emissions decreased
- The majority of the particles by number evaporated upon heating, suggesting that particles are predominantly internally mixed and semi-volatile

Thank you!

See also:

SESSION 9 – Particulate Matter

Wednesday 4/2/08

3:25 PM Presentation

Air Toxic Emissions from HD Diesel Vehicles Equipped with NOx and PM Retrofits

M.-C. Oliver Chang, Yanbo Pang, Paul Rieger, Jorn D. Herner, Tao Huai, Mark Fuentes, and Alberto Ayala